LESSON 27 – DOPPLER'S EFFECT ON SPECTRA

In this lesson, we'll examine how Doppler techniques simplify the processing of some data while they make other analyses much more complicated.

Reading:
Stimson **Ch. 16-17**

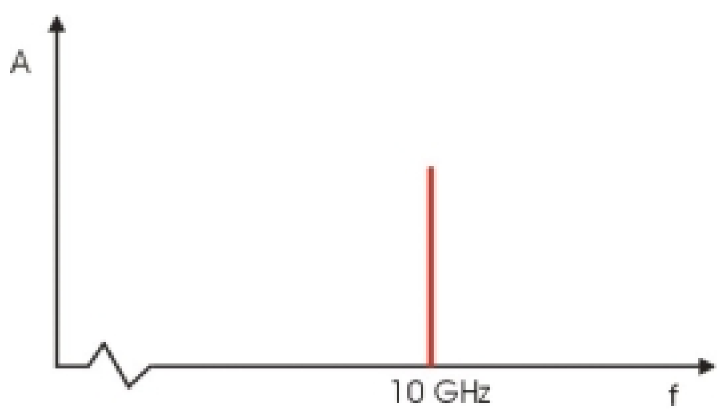
Problems/Questions:
Work on Problem Set 4

Objectives:
- 27-1 Understand what a coherent and an incoherent pulse is.
- 27-2 Understand the purpose of a Fourier transform.
- 27-3 Know what is meant by a frequency spectrum.
- 27-4 Understand how pulse duration affects the pulsed spectrum.
- 27-5 Understand how the number of pulses affects the pulsed spectrum.
- 27-6 Understand how pulse repetition frequency affects the pulsed spectrum.

Last Time: Doppler shift
- wave explanation
- phasor explanation

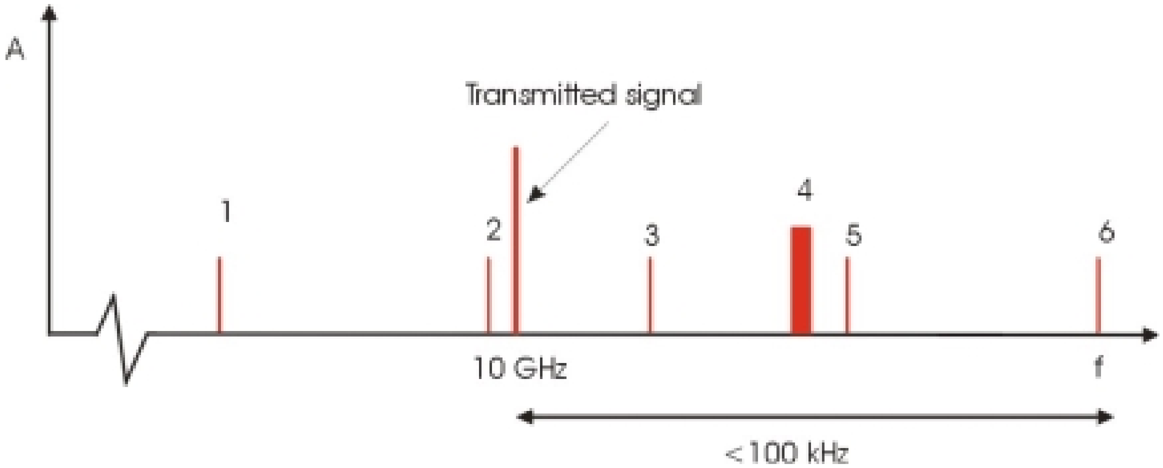
Today: Pulsed Spectra
- Why a single frequency isn't
- Coherence
- Pulse width effects
- Pulse Repetition Frequency effects
- Fourier Transforms

Equations: $BW_{nn} = 2/\tau$



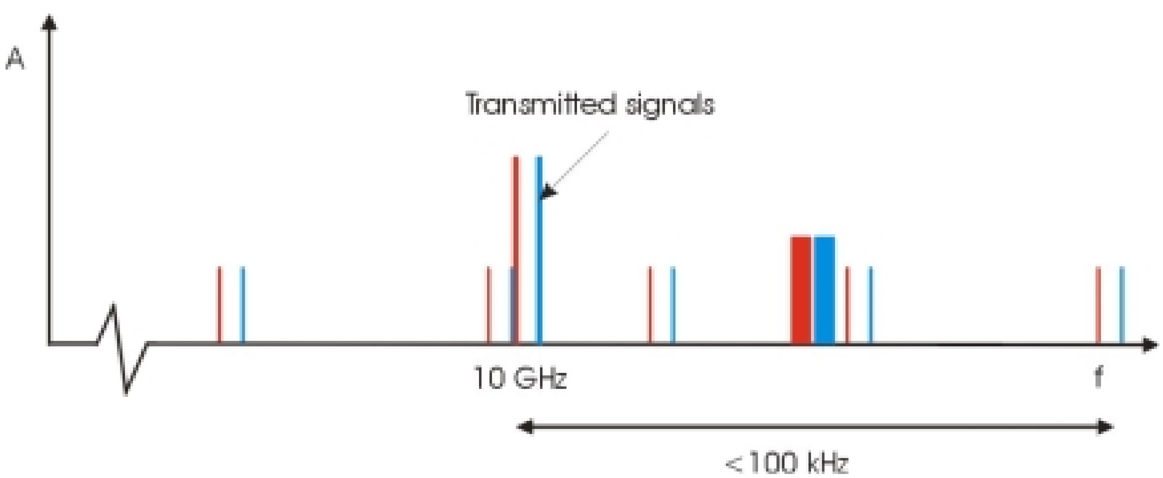
What is a typical radar frequency? Plot this on A vs F as a spike at 10 GHz.

What is a typical returned frequency? The same, more, or less? Plot these on the same graph. Discuss relative speeds of targets that caused the returns. What does this tell us?

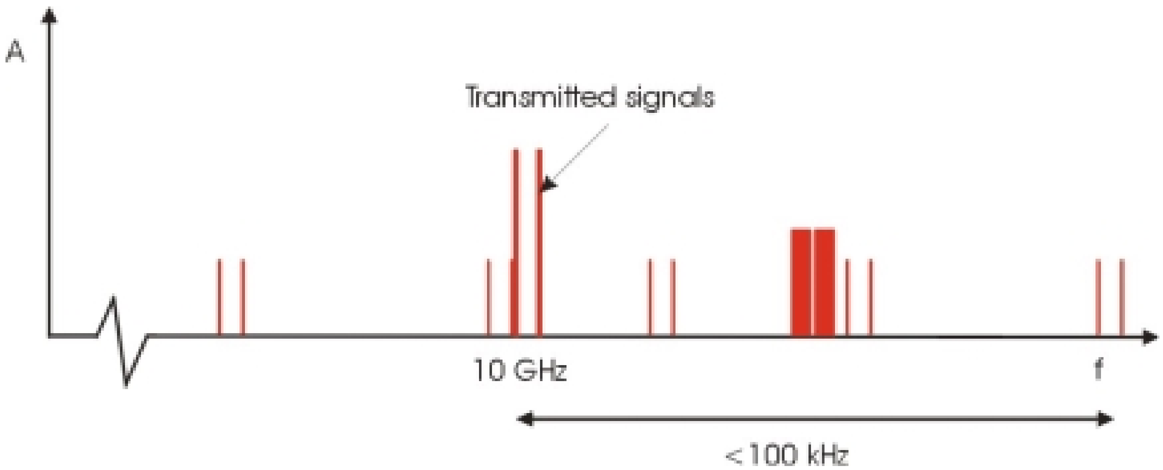


Return 1 is opening rapidly ($v = 2v_{fighter}$). Return 2 is barely opening. Return 3 is moderately closing ($v = 1/2\ v_{fighter}$). Return 4 is ground clutter . Return 5 has almost the same closure as the ground. Return 6 has high closure, $v = -v_{fighter}$

Now, let me add a bit of confusion: What if our "single frequency we are transmitting is now actually transmitted at two frequencies? What would the return look like?
(DRAW THIS IN TWO COLORS)

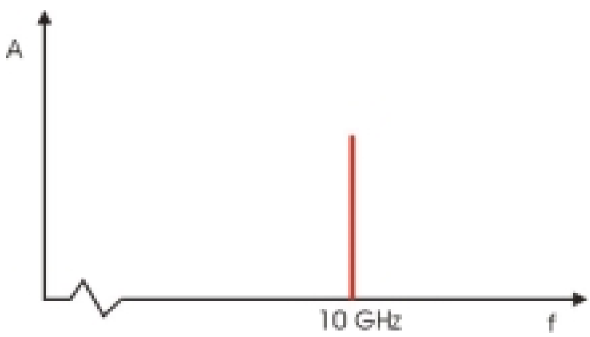


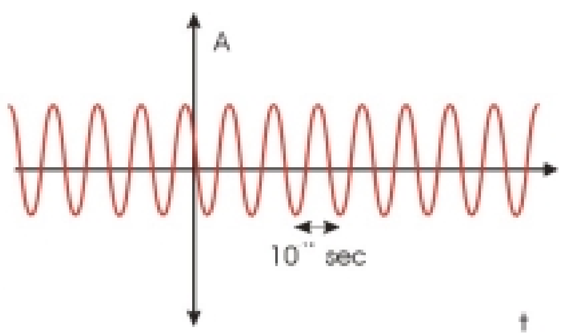
It's easy to see with two colors which returns are associated with which transmitted signal, but what if they're all the same color? The radar doesn't know which return is associated with which transmission!



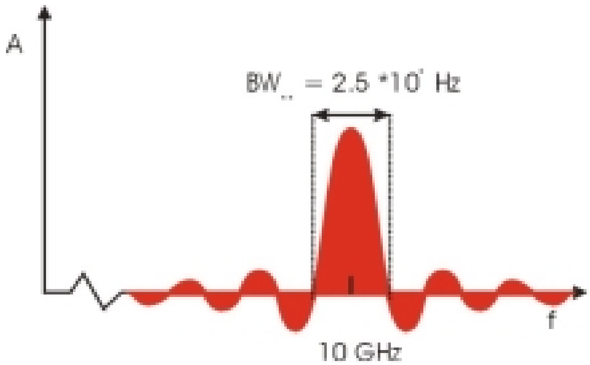
Why do I bring this up? Because we NEVER transmit at a single frequency NO MATTER HOW HARD WE TRY!!!

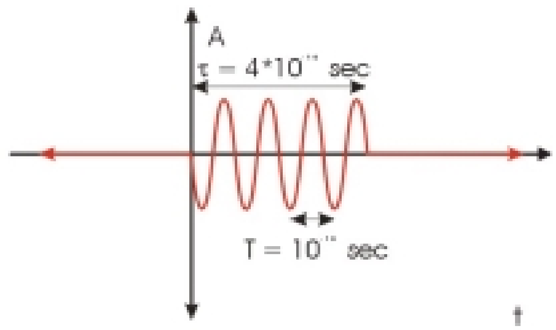
Show what the differences between infinite wave spectra and pulse spectra are.





This pair of figures is an infinitely long (in time) sinusoidal wave oscillating at f_0 = 10 GHz.

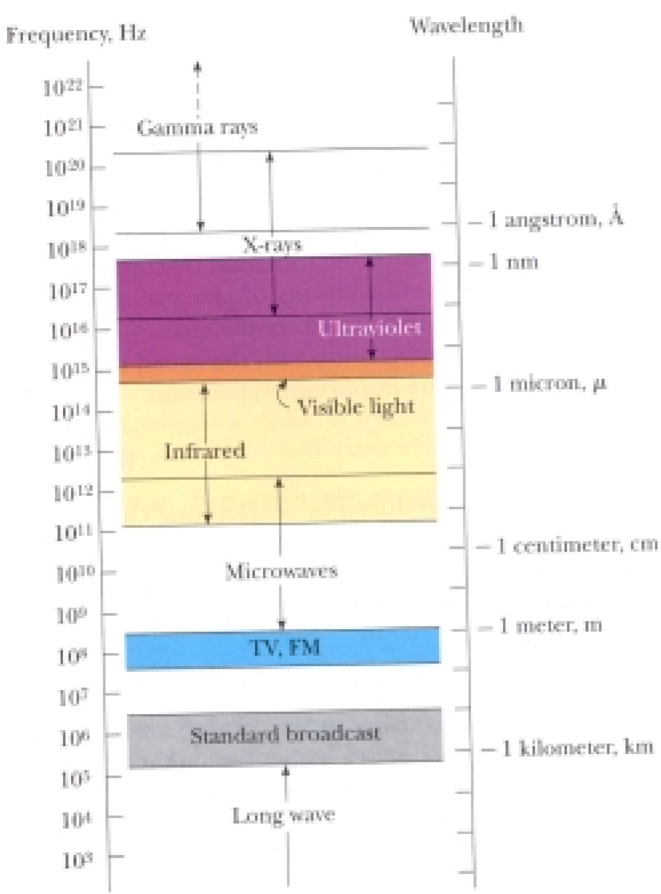




This pair of figures is a single pulse with a carrier frequency of f_0 = 10 GHz and a pulse width of τ.

Notice that MANY frequencies are necessary to generate the pulse.

We'll see that the null-to-null bandwidth (BW_{nn}) is related to the pulse width, τ by the relation $BW_{nn} = 2/\tau$. This says the shorter the pulse, the broader the frequency spectrum required to generate it.



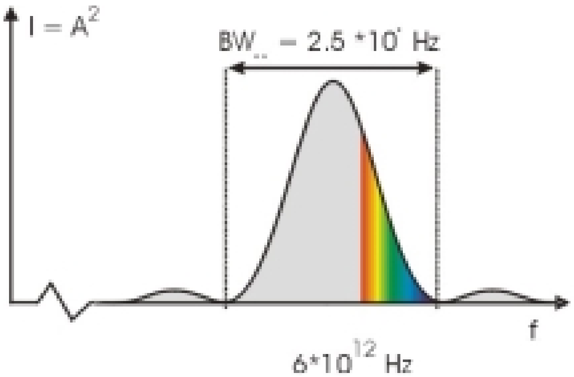
An example is that the University of Texas' Femtosecond laser built by M. Downer has a lasing transition of 25meV , or $4x10^{-21}$J, or $6x10^{12}$Hz or 50,000 nm. For reference, the wavelength of visible light is about 400 to 700 nm. Comparing these three values implies that we shouldn't be able to see this laser.

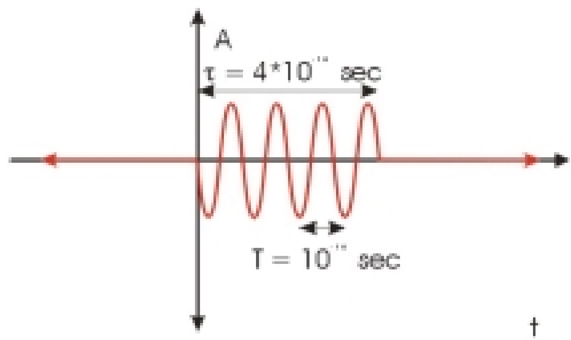
Show the slide of the spectrum from Serway, Fig 24.13.

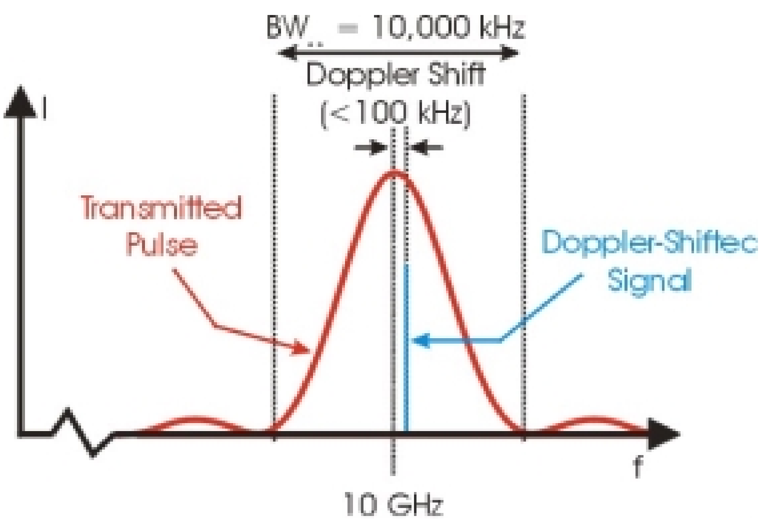
Question: Can you see these pulses? Answer: YES!

Question: How? It is a very special laser with a pulse width of only $1x10^{-15}$ sec. Is that time short? Compared to what?!! The difference between the time of this pulse and a second is equivalent to the difference in size between a proton and a meter, or the difference in size of your palm and the solar system – this is a VERY short time!

$\Delta f = 2/\tau = 2x10^{15}$ Hz => the top frequency of this laser pulse is $6x10^{12}$ Hz + $1x10^{15}$ Hz = 1.006 x 10^{15} Hz = 300 nm.





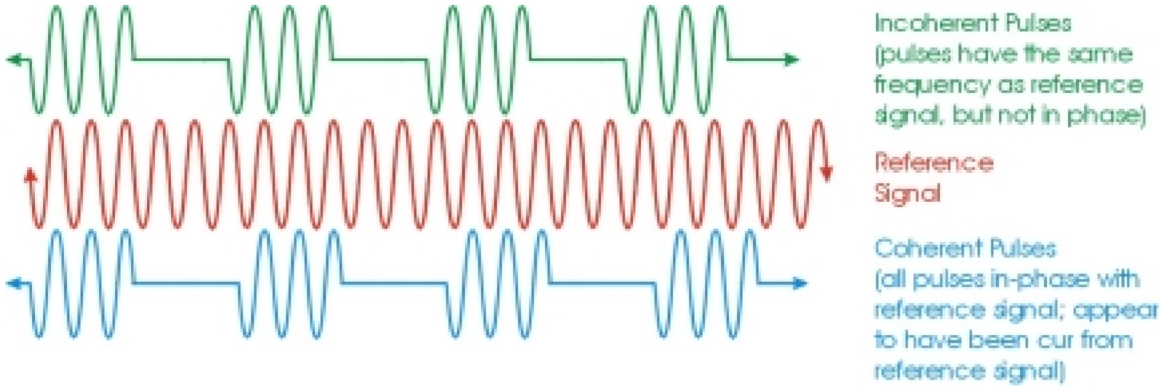


A typical radar pulse width is about 200 ns. How wide is this pulse in frequency? 10,000 kHz! How much was the typical Doppler shift? 100 kHz. Our Doppler shifted return is now hidden in the spectrum of the transmitted signal.

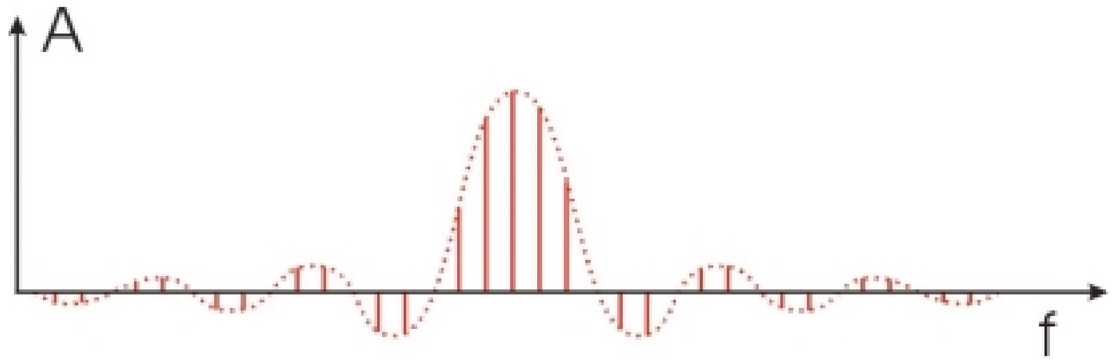
Obviously, since Doppler radars do work, this problem has been resolved (so to speak). How?

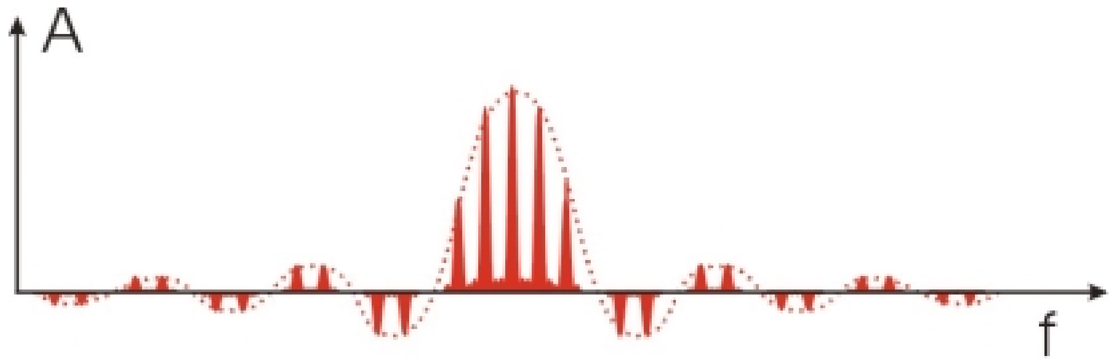
To understand this, we must understand the concept of coherence. Coherence means that the pulses look like they were cut from the same CW. For coherent pulses, there are many fewer frequency components.

Show slide of coherent vs. incoherent pulses. Talk about how they are simple to generate with a continuously operating wave generator that is hooked intermittently to the transmitter.



With an INFINITE string of coherent pulses, the spectrum is strikingly different.





With a FINITE string of coherent pulses, the individual lines broaden as Linewidth = $(2/N)f_r$, where N is the number of pulses and f_r is the PRF.

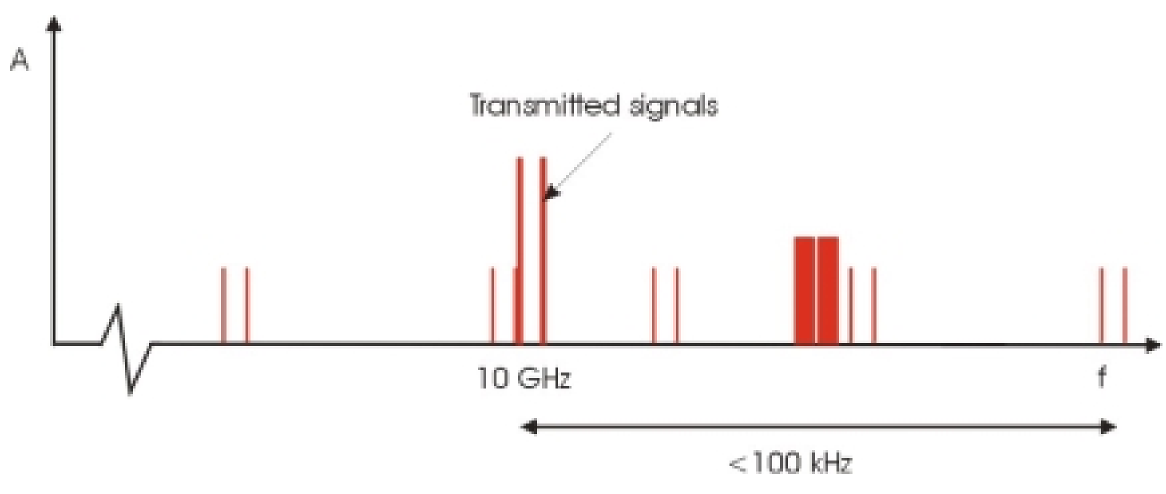
So why does this happen? Let's look at Fourier Series.

ANY (periodic) function may be approximated by adding together a set of sine and cosine waves. Any function may be EXACTLY duplicated by adding up an INFINITE set of sine and cosine waves.

Show CUPS Fourier demo for an arbitrary curve, a single pulse, a grating with different pulse widths.

The Fourier equation is $\sum_{n=0}^{\infty}[a_n \cos(n\omega t) + b_n \sin(n\omega t)]$, where the a_n's and b_n's are the amplitudes of the constituent frequencies. This says that any function F(x) may be written as the sum of a series of sines and cosines with various amplitudes. Actually figuring out what these amplitudes are is beyond the scope of this course, and you may have already done it in some of your math courses. What I want you to know is that for any signal other than an INFINITE sine/cosine wave, the spectrum of this signal MUST contain multiple frequencies.

The question still remains: with multiple transmitted frequencies, how do we find the TRUE Doppler?



We'll examine this in the next lesson's computer application.